Hemispheric albedo asymmetries in CERES and CMIP

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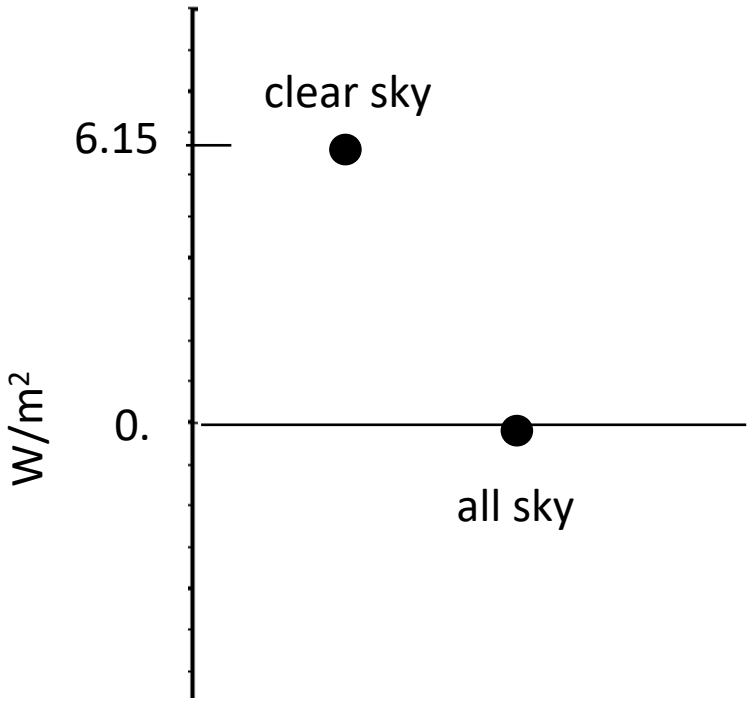
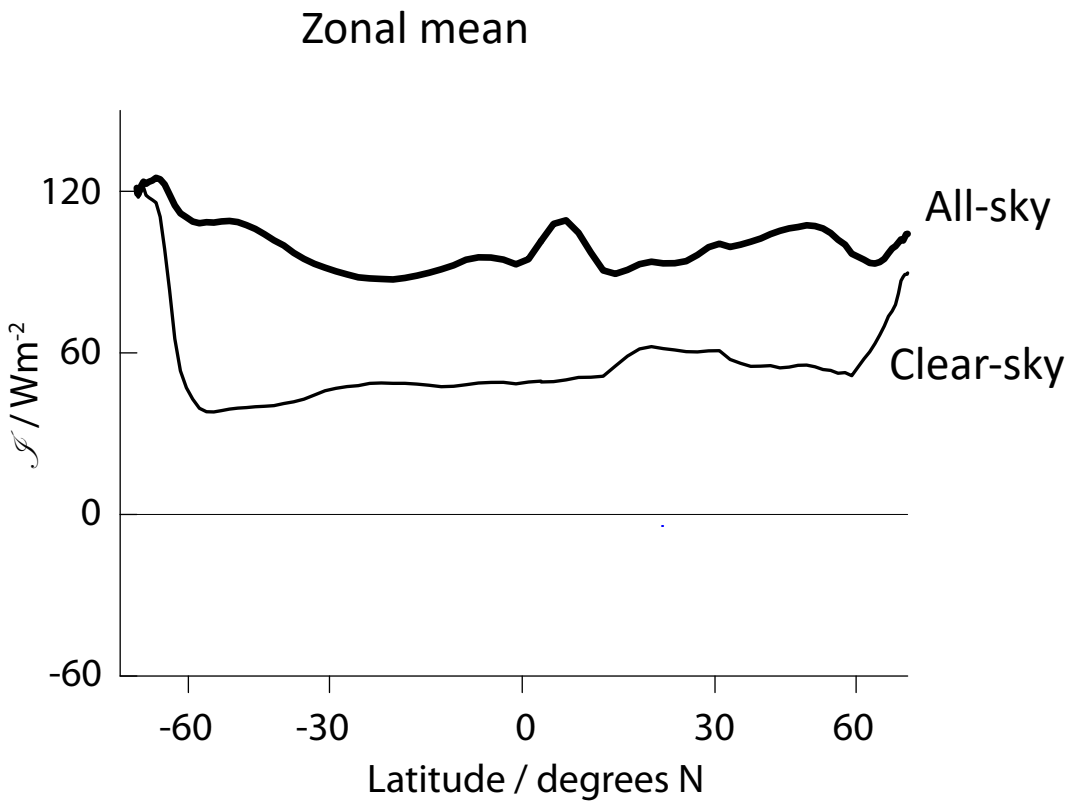
Max-Planck-Institut
für Meteorologie

Clear sky TOA SW upward radiation is hemispheric asymmetric (6.15 W/m^2)





Surprisingly, TOA SW all-sky upward radiation is almost hemispheric symmetric

Why do we have a hemispheric symmetry in TOA SW reflection?

Is the symmetry by chance?

1. What does contribute to the hemispheric symmetry in the satellite data (CERES)?
   - what is the role of clouds?
   - are there crucial regions?

→ Decomposition into surface/atmosphere and cloud/clear-sky contributions

2. Do we find a hemispheric symmetry in GCMs with similar contributions as in CERES?
   - Are there improvements across CMIP phases?
   - Are there common systematic biases in the GCMs?

→ Cloud masking effect on hemispheric asymmetry

Decomposition into surface/atmosphere and cloud/clear sky contributions

All-sky (F)

$$F = F_{\mathrm{srf}} + F_{\mathrm{atm}}$$

$$F_{\mathrm{atm}} = \frac{F - \alpha_0 \mathscr{T}_{\mathrm{atm}}{}^2 S}{1 - (\alpha_0 \mathscr{T}_{\mathrm{atm}})^2}$$

F	all-sky TOA reflection
G	clear-sky TOA reflection
α_0	Surface albedo
$\mathscr{T}_{\mathrm{atm}}$	Atm. transmissivity
S	Insolation

(Donohoe & Battisti, 2011)

Similar for clear-sky (G)

Cloud contributions to atmospheric / surface component of TOA SW reflection

$F_{\mathrm{atm}} - G_{\mathrm{atm}}$ and $F_{\mathrm{srf}} - G_{\mathrm{srf}}$

Cloud masking effect on hemispheric asymmetry

No clouds ➔ all-sky asymmetry = clear-sky asymmetry

Clouds symmetric w.r.t. equator ➔ all-sky asymmetry < clear-sky asymmetry

-> misleading to compare hemispheric asymmetries in the all-sky and clear-sky reflections

Define reference hemispheric asymmetry, assuming symmetric cloud radiative effects ($\Delta\tilde{F}$)

$$\Delta\tilde{F} = \bar{\gamma}\Delta G$$

ΔG Hemispheric difference clear-sky F

$\bar{\gamma}$: Symmetric w.r.t. the equator

F_{srf} *Surface contribution to F*

G_{srf} *Surface contribution to G*

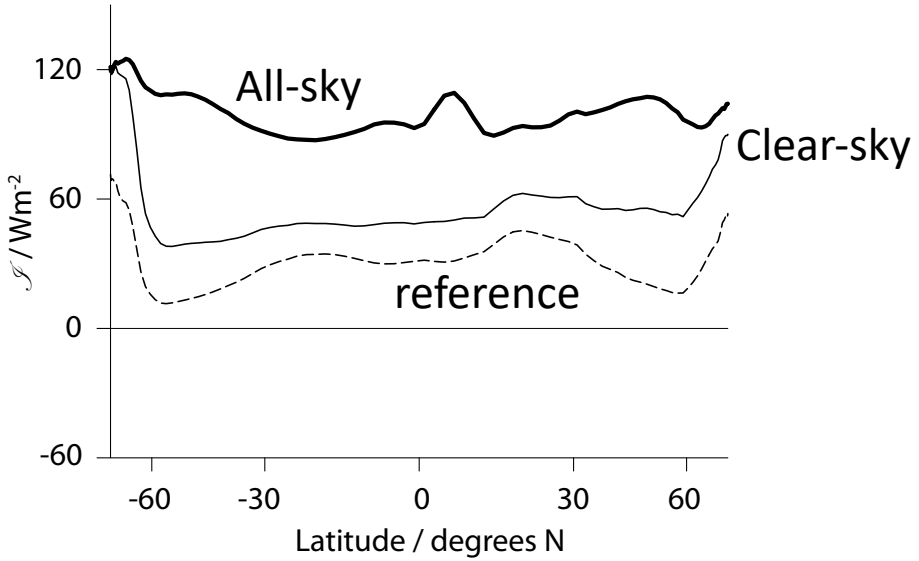
Attenuation of clear-sky surface reflection by clouds:

$$\gamma = \frac{F_{\mathrm{srf}}}{G_{\mathrm{srf}}}$$

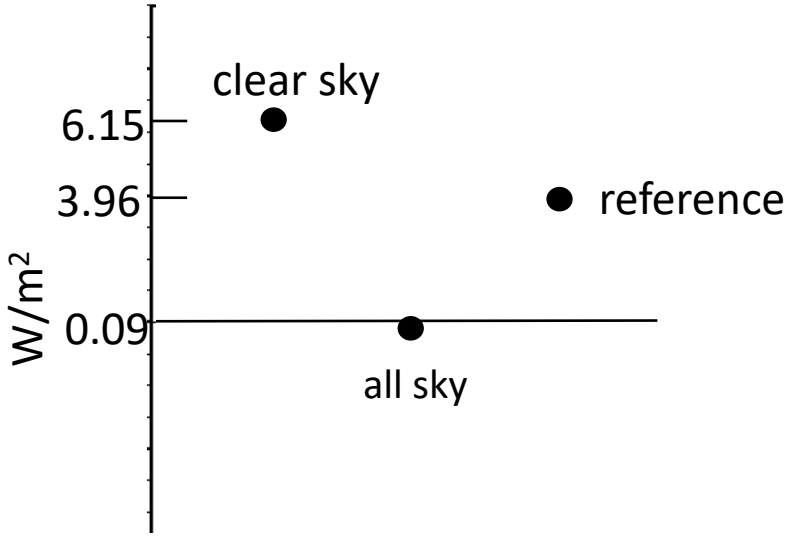
Compensation mechanism only, if all-sky reflection below reference

CERES TOA SW reflection

Zonal mean

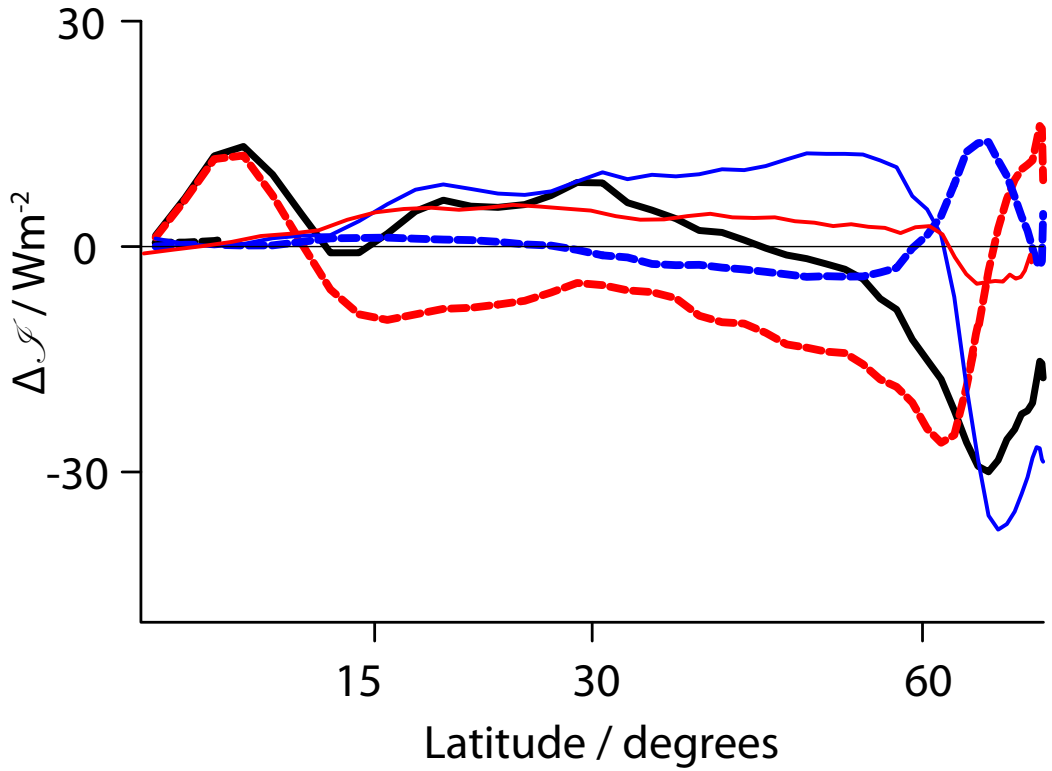


Hemispheric differences



More than half of clear-sky asymmetry is compensated by asymmetric cloud radiative effects

CERES NH-SH zonal mean asymmetries



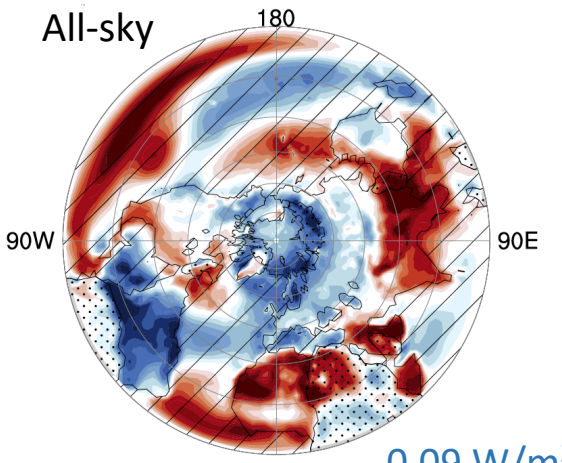
	NH-SH (W/m^2)
All-sky	0.09
Surface clear-sky	2.04
Surface clouds	0.21
Atmosphere clouds	-6.27
Atmosphere clear-sky	4.11

- Atmosphere cloud contribution enhance clear-sky asymmetry in the tropics. Overall compensation in (sub-)polar region
- Surface contributions large over polar regions

→ Polar/subpolar area and tropics crucial regions

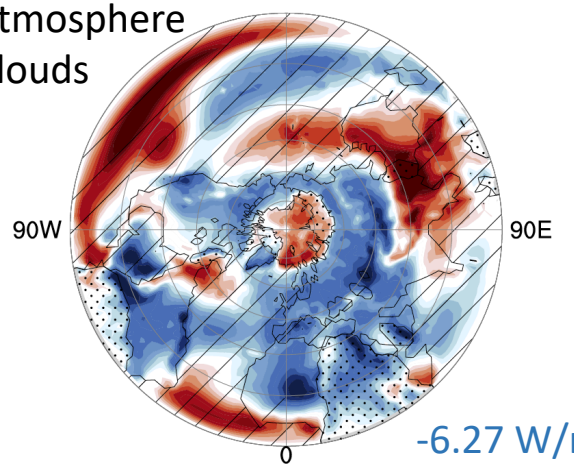
CERES NH-SH asymmetries

All-sky



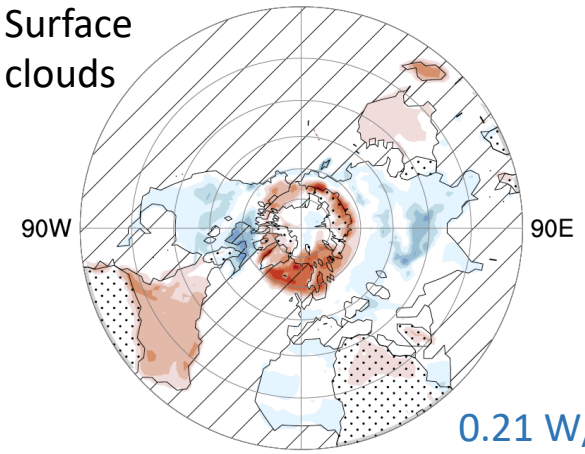
0.09 W/m^2

Atmosphere Clouds

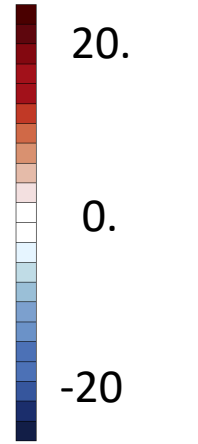


-6.27 W/m^2

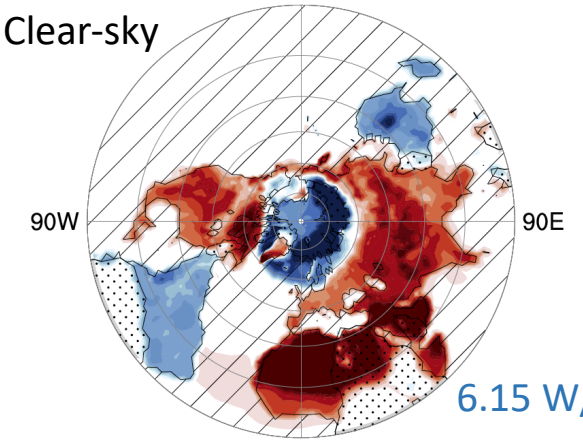
Surface clouds



0.21 W/m^2

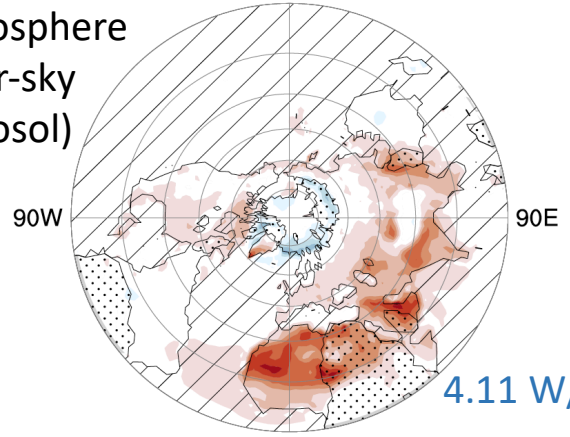


Clear-sky



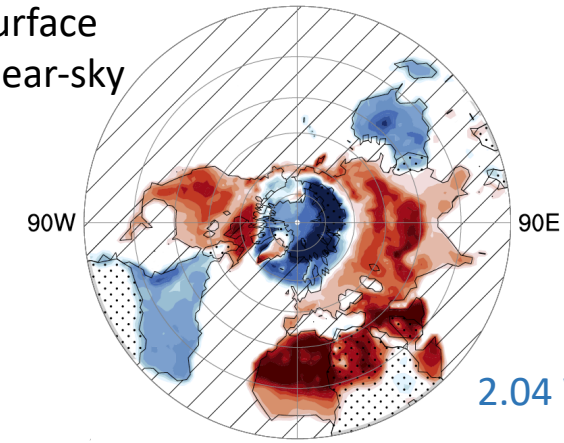
6.15 W/m^2

Atmosphere clear-sky (Aerosol)



4.11 W/m^2

Surface Clear-sky

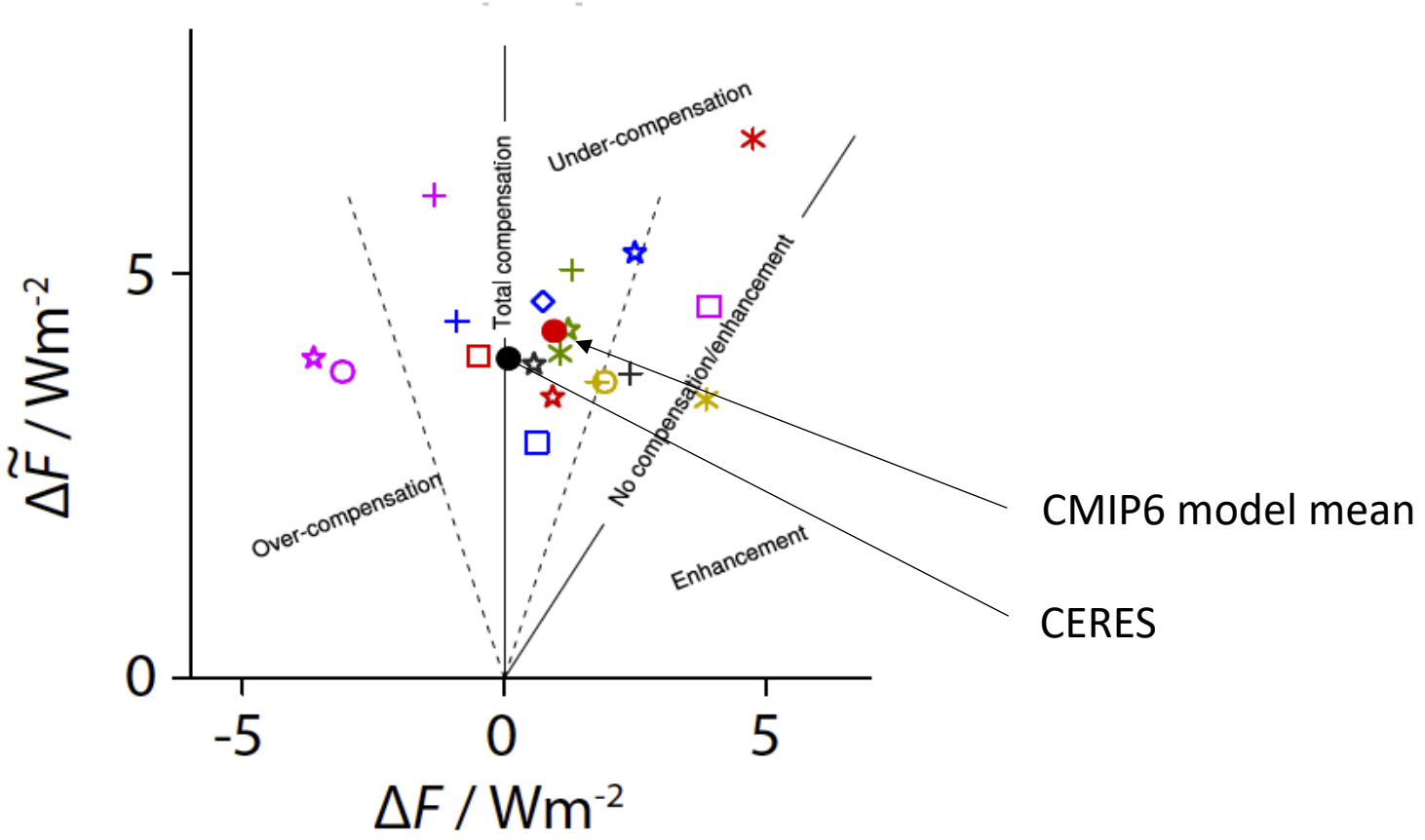


2.04 W/m^2

- Similar atmosphere cloud and all-sky pattern, the former providing compensation
- Surface clouds contribution small
- Aerosol effect on northern hemisphere larger than in the south, dominating clear-sky asymmetry

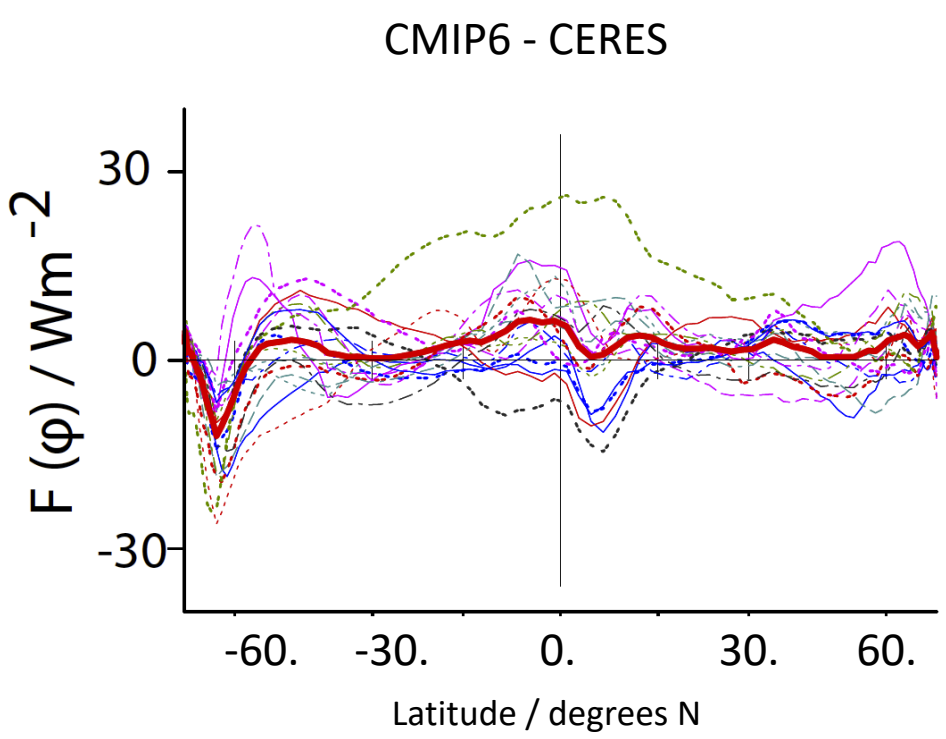
Compensation also in CMIP?

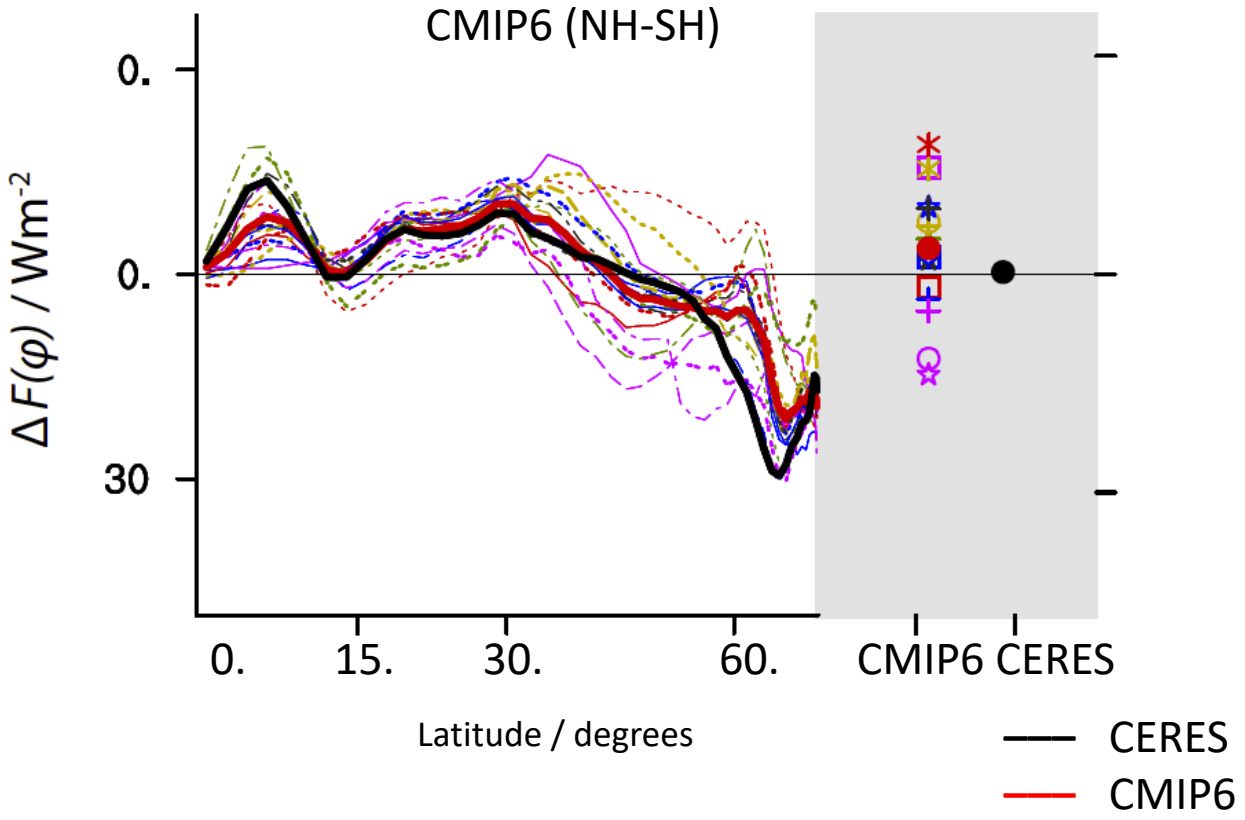
CMIP6 compensation



- Almost all CMIP6 GCMs show compensation
- CMIP6 model mean shows slight undercompensation (ΔF = 0.96 W/m2)

CMIP6 all-sky zonal means





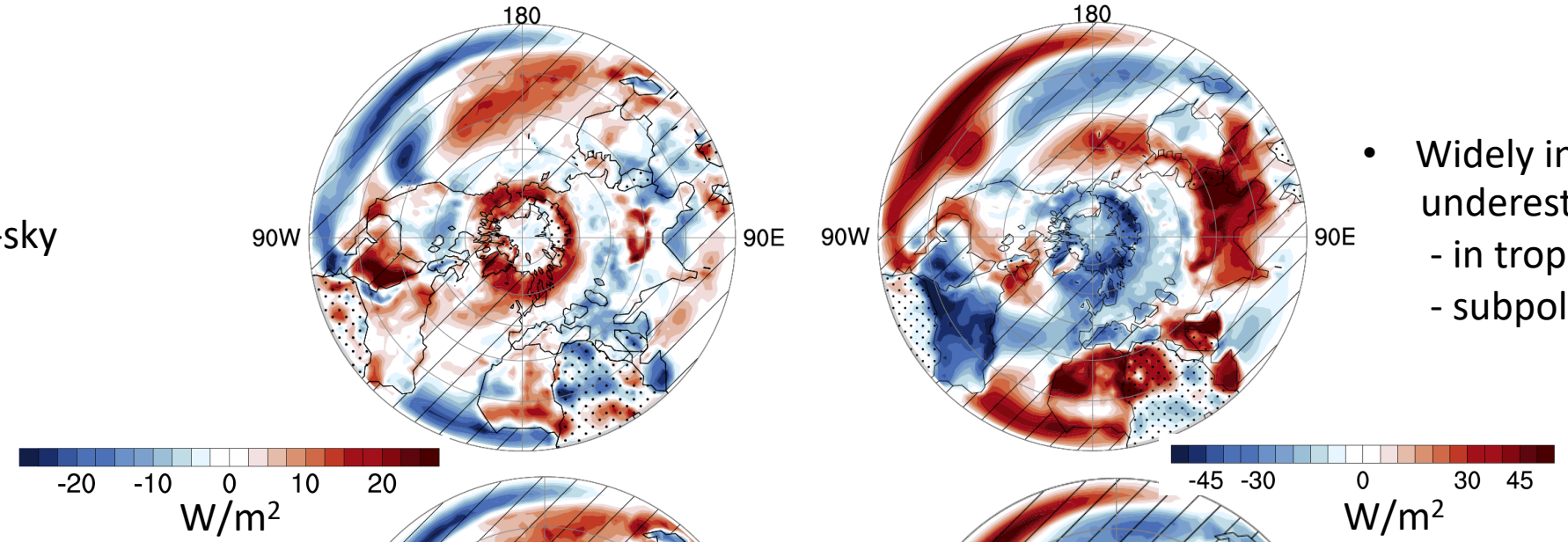
- Large spread of GCMs
- main biases in south polar and south tropical regions

- Hemispheric difference biases in tropics and polar regions compensate
- elsewhere negligible biases

CMIP6 - CERES

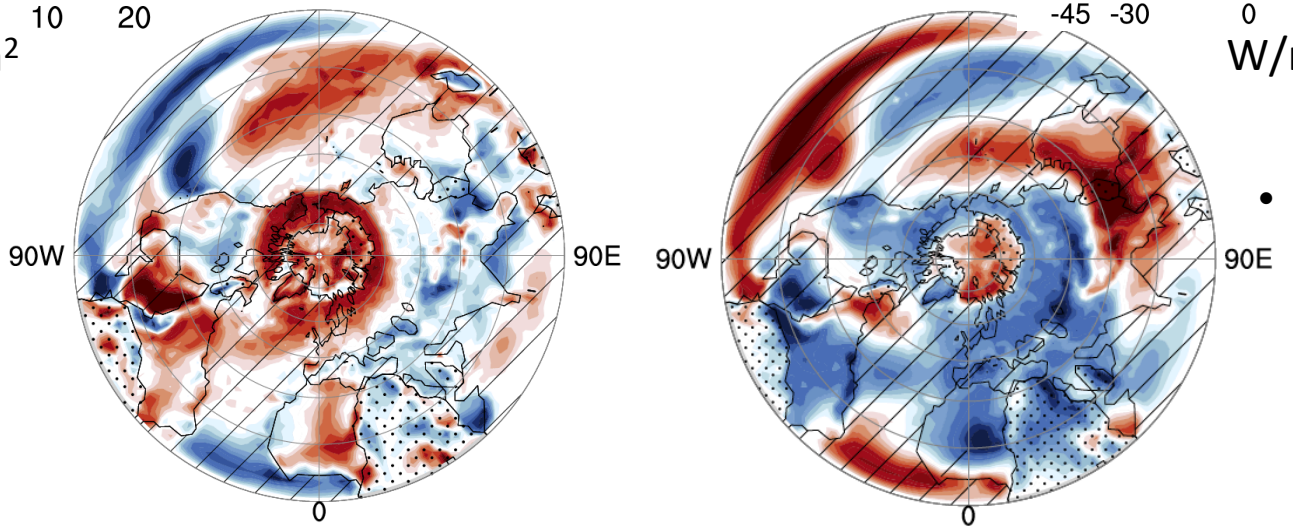
CERES

All-sky



- Widely invers pattern, i.e. CMIP6 underestimates reflection asymmetry,
  - in tropical Atlantic/Pacific and
  - subpolar regions

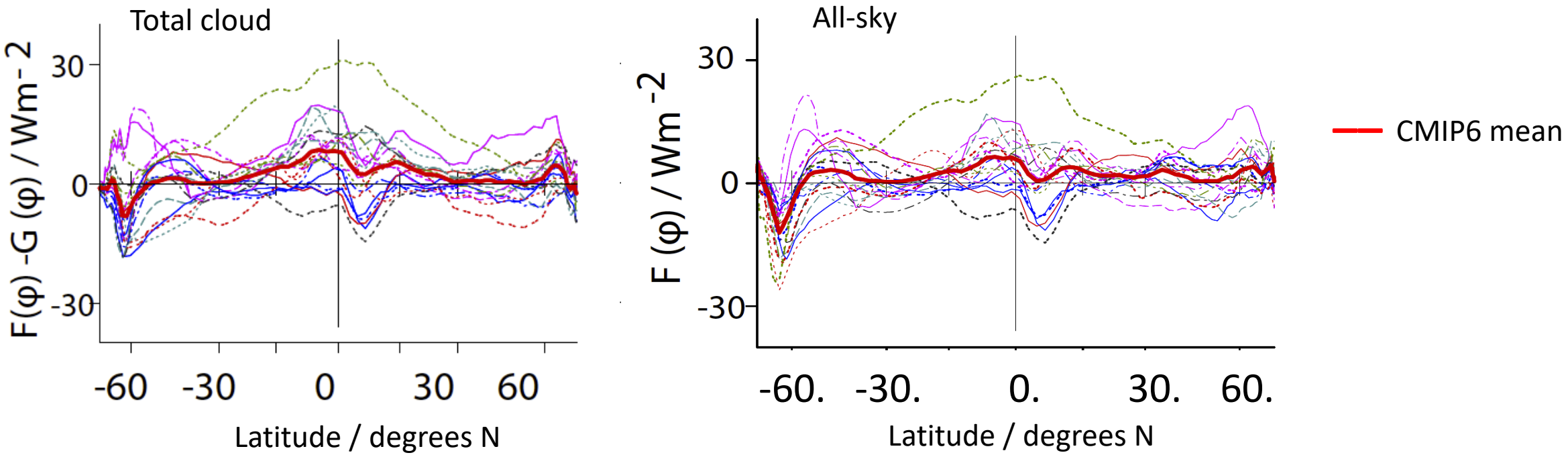
Atmosphere clouds



- Similar invers pattern, also widely underestimation.

CMIP6 model mean underestimates atmosphere cloud contributions

CMIP6 total cloud bias

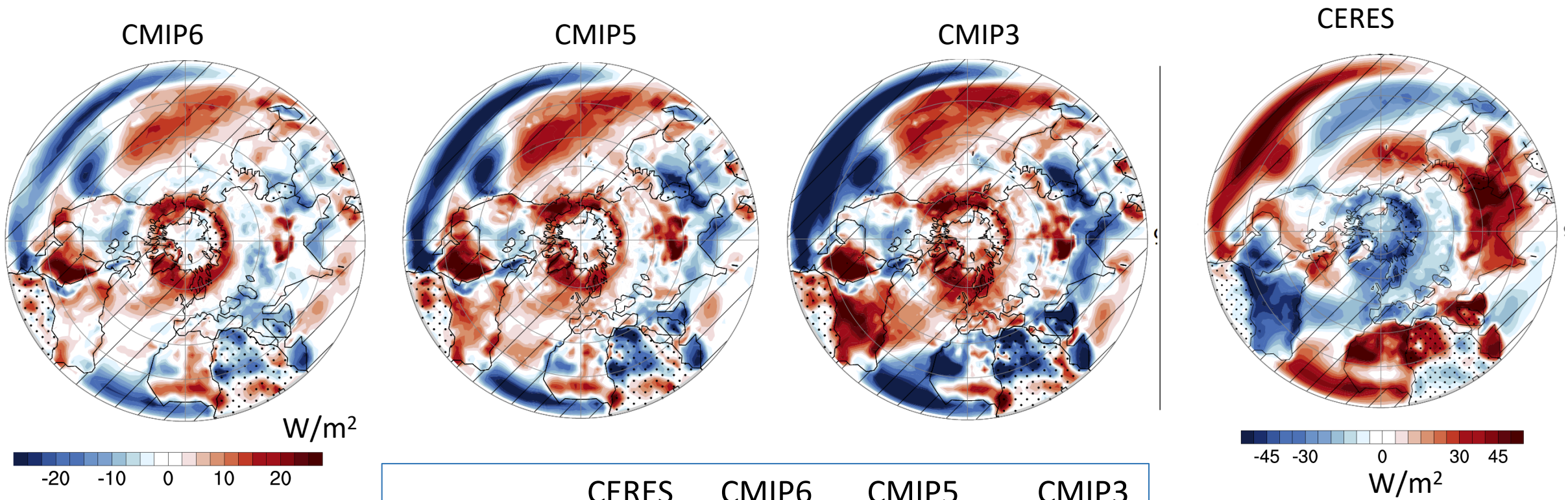


- Similar biases in total clouds and all-sky
- Accumulating biases in polar areas, compensating biases in tropics

→ Cloud radiative effect biases dominate all-sky bias

Improvement across CMIP phases?

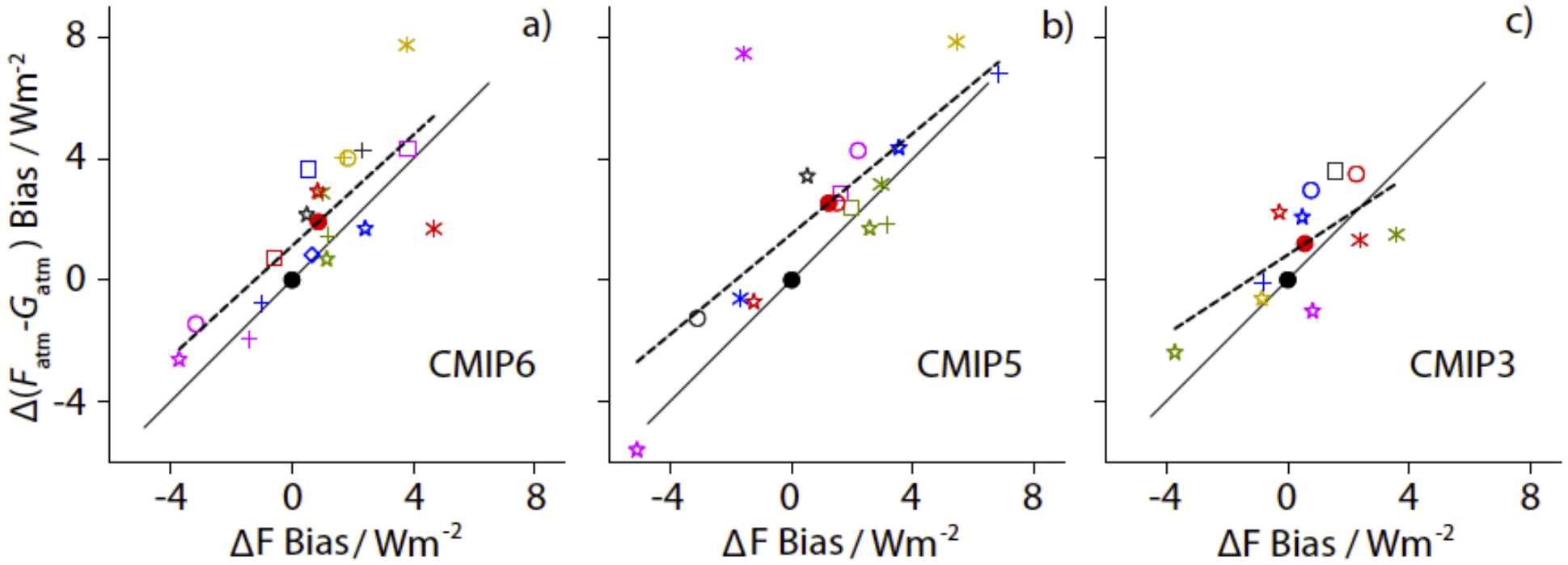
All-sky biases



	CERES	CMIP6	CMIP5	CMIP3
ΔF	0.09	0.96	1.31	0.65
ΔF RMSE		9.02	11.52	14.03

- Total asymmetry suggests no improvement, but pattern and RMSE do.
- In all CMIP phases spatially compensating biases.

CMIP cloud biases



In CMIP6, biases of individual Δ*F* are mainly do to Δ(F_{atm} – G_{atm}) biases

Conclusions

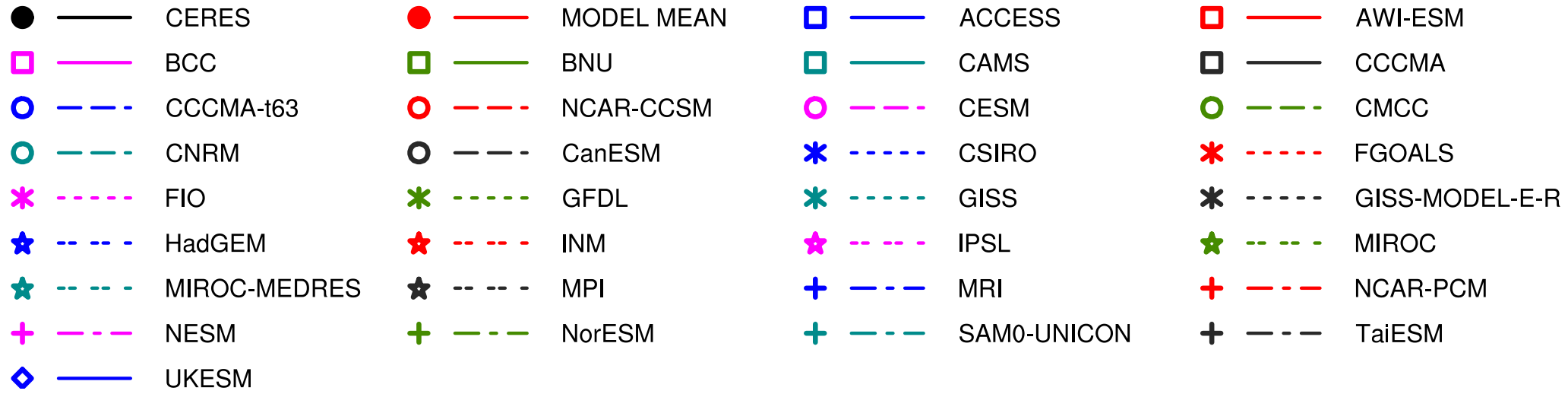
- CERES shows almost perfect hemispheric symmetry of TOA reflection in contrast to land surfaces and aerosols, which introduce asymmetry of 6.15 W/m^2.
- We ask for the role of clouds, following Donohoe and Battisti (2011), and separate role of clouds in masking and compensating clear-sky asymmetry.

- CERES extratropical clouds play dominant role in compensation process.
- Tropical clouds enhance reference asymmetry.
- Extratropical clouds balance both, reference and asymmetry introduced by tropical clouds.
- Additional tropical asymmetries originate in east Pacific and Atlantic regions; west Pacific hardly contributes.

- CMIP-multi-model means show similar reflection properties as CERES.
- Mean asymmetry is smallest for oldest GCMs. However, spatial patterns indicate improvements going from CMIP3, to CMIP5 and CMIP6.
- Mean biases, but also the bias pattern of hemispheric all-sky differences are strongly related to cloud contribution biases.

→ Clouds do not only compensate, but are also main source of remaining biases in CMIP.

Crueger, Schmidt, Stevens, in prep.


CERES
BCC
CCCMA-t63
CNRM
FIO
HadGEM
MIROC-MEDRES
NESM
UKESM
MODEL MEAN
BNU
NCAR-CCSM
CanESM
GFDL
INM
MPI
NorESM
ACCESS
CAMS
CESM
CSIRO
GISS
IPSL
MRI
SAM0-UNICON
AWI-ESM
CCCMA
CMCC
FGOALS
GISS-MODEL-E-R
MIROC
NCAR-PCM
TaiESM

$\Delta F_{srf}, \Delta F_{atm}$ *(all-sky)* and $\Delta G_{srf}, \Delta G_{atm}$ *(clear-sky)*

$\mathscr{J}$	F	G	$\tilde{F}$	F_{srf}	G_{srf}	F_{srf}-G_{srf}	F_{atm}	G_{atm}	F_{atm}- G_{atm}
Hemispheric difference	0.09	6.15	3.96	2.25	2.04	0.21	-2.16	4.11	-6.27

Surface contribution by clouds

Atmosphere contribution by clouds

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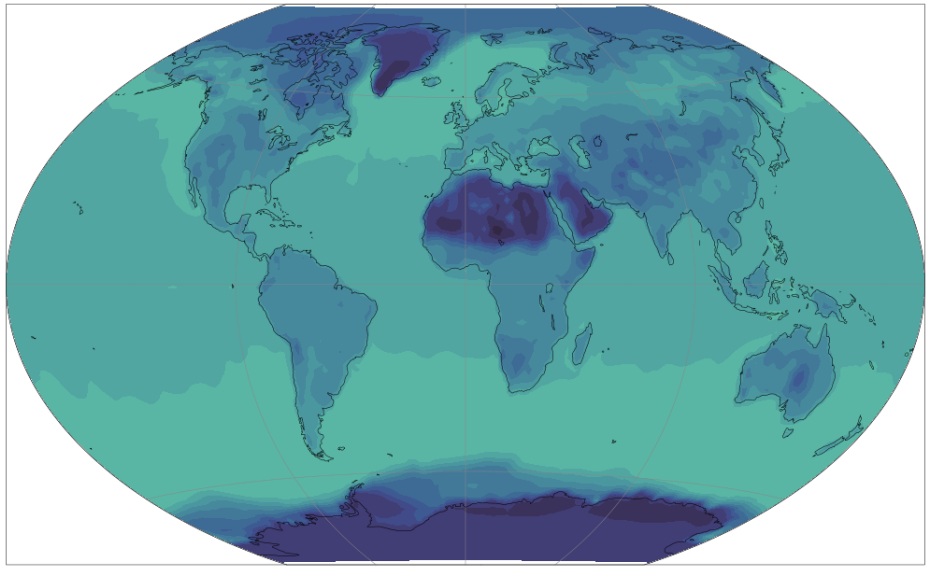
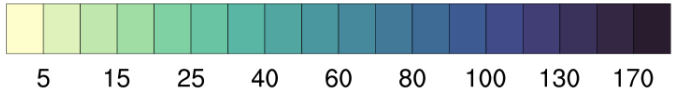
CERES

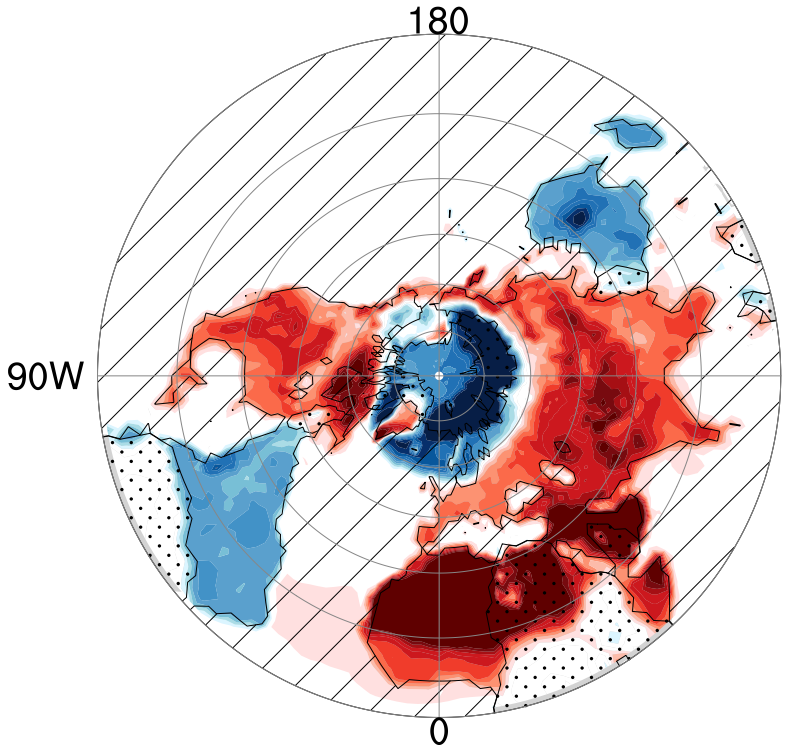
Clear-sky

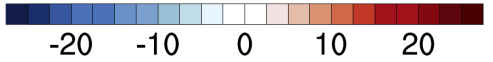




W/m²

Clear-sky NH-SH difference (north polar projection)





W/m²

Ocean/ocean areas: Hatched

Land/land areas: dotted

Land/ocean and ice areas dominate pattern

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